Semantic Synchronization of Key Registers in a Model for Drinking Water Resources Management

Milorad K. Banjanin, Danka Ćulum-Miladinović, Goran Drakulić, and Branislav Drašković

***Abstract* — Research was oriented to spatial-cadastral information-presentation system (SCIPS) and its application to the process of drinking water resources management, with the aim of improving the quality and availability of spatial and other relevant data about these resources. Authors define a model of drinking water resources management on a SCIPS platform, which improves the efficiency of information exchange in the individual interactions of social, government and private participants witch supply users with drinking water. The model is oriented to achieving a high level of availability and multiple uses of data in a wider geographic area based on the principles of cooperation, coordination and collaboration of various elements in a drinking water distribution system. Application of that model, in which key registers are semantically synchronized, may provide more rational and more sustainable usage of drinking water resources and avoiding of potential conflicts of interest or jurisdiction over those resources.**

***Keywords* — Drinking Water Resources, Information Communication Technologies, Interoperability, Ontological Engineering, Semantic Synchronization of the Key Registers, Spatial-Cadastral Information-Presentation System, Spatial Data, Spatial Information Infrastructure.**

I. Introduction

DRINKING water resources have a special role in human future, and high-quality, timely and reliable data and information in an observed area are of increasing importance for strengthening that role. Special requirements are related to the enhancement of these resources potential estimates based on new knowledge about the complex interactions of water, nature and humans. [13] At the same time, making strategic and operational decisions in a water supply system is in a function of quality of these requirements and their solution.

The system of integrated drinking water resources management in some area requires displaying of data in a geospatial coordinate system and linking geospatial information on water characteristics of a terrain with a time series of measurements. The primary structures for the presentation of a larger space are presented in a vector form, supported by a raster base and possibly a Triangulated Irregular Network (TIN) display of the terrain. Planning and creating a unique information structure of drinking water resources includes the following principles of organization: compliance of the objectives, standards of water supply facilities identification, compliance of the key registers content, the unity of the communication network, compliance of the system programs support, a unique database, technological compatibility of the equipment and completeness of the information connection of all subjects.

Corresponding Prof. PhD Milorad K. Banjanin, is now with the Faculty of Technichal Sciences, University of Novi Sad, Serbia; (phone: 381-64-4910000; e-mail: mkb252633@eunet.rs).

MSc Danka S. Ćulum is with the JP PTT traffic "Serbia", 21000 Novi Sad, Serbia; (phone: 381-64-2647383; e-mail: dankamil@sezampro.rs).

MSc Goran D. Drakulić is with the JP PTT traffic "Serbia", 21000 Novi Sad, Serbia; (phone: 381-64-1465215; e-mail: drakulic@hotmail.com).

MSc Branislav Drašković is with the Philosophy faculty Pale, University of Istočno Sarajevo, Istočno Sarajevo; (e-mail: draskovic.branislav@gmail.com).

II. Spatial-Cadastral Information-Presentation System for Water Supply Management

Spatial-Cadastral Information-Presentation System (SCIPS) is defined as a complex interaction matrix of the elements of technical, technological, organizational, economic and legal functions for the planning, implementation and control of integral drinking water resources management that meets the identified needs and requirements. Generating reliable, comparable and accessible data and information includes the appropriate organizational integration of Geographic Information System (GIS) [5] with other functional-application software (e.g. Arc Hydro) and associated databases, as well as the interoperability of modern technological solutions in the water supply system with the management of financial, material and human resources. So, a SCIPS is required to be a reliable and comprehensive, interoperable information-presentation system accessible to a wide range of users in the local/national government and in the public.

In a general case, a SCIPS is structured by a Spatial Information Infrastructure (SII), ICT equipment and procedures/processes required for collecting, sorting and analysing data, as well as generating, evaluating and disseminating timely and accurate information. The idea is to implement a SCIPS in the water supply system to enable complete digitalized and documented workflows transparency, achieve coordination of all stakeholders and ensure their visibility, for the purpose of making quality strategic and operational decisions in drinking water resources managing. Storage, processing, presentation and distribution of relevant spatial and non-spatial data, to the interested parties for their use (the relevant institutions, facilities for the processing of raw water, private bottled water factories, customers, etc.) can be evaluated as a primary goal of the application of SCIPS in drinking water resource management.

In traditional, but highly dynamic business systems, such as water supply systems, the relevant spatial and non-spatial data are usually stored on different locations and in different data models. [3] But, even the simple entity vector models of points, lines and polygons are not the most appropriate for presentation, modelling and manipulation of hydrological phenomena. This problem exists because the change in geometry means a change of coordinates and topological data in a network of polygons, which requires complex calculations.

Therefore, it is better to use a model based on the use of authentic registers (or "key registers") for storing the key data that are interoperable and available for integration and reuse, and also allow the connection of primitive entities in functional groups. The internal structure of the key registers allows that the effect on one component of the group to be automatically transferred to other parts. Accordingly, the key registers not only contain a geographic location, geometry, topology and attributes, but also information on how they react to changes. Therefore, the use of SCIPS must be based on fully defined key registers from all areas of creating new values that are somehow linked to water supply systems.

SCIPS is the system with the so-called full structure, meaning that all its subsystems (as information network nodes) can directly communicate with each other. This improves the operability, functionality, consistency and reliability of all participants in the chain, which occur as both providers and users of information. In that context, the full structure of the system consists of the following components: target (goal or a set of goals in water supply processes), organizational (the set of elements and components of the mutual relationships that form the topology of SCIPS), functional (activities carried out during the conversion of inputs into outputs), information (the totality of semantic representation of relevant spatial and non-spatial data with which and over which it performs functional transformations), communication-interaction (relationships between the elements of SCIPS and system connections with the environment, that are created and maintained in the process of exchanging information) and management structure (adjusts the overall SCIPS behaviour in the water supply processes).

A. *General Architecture of SCIPS*

The design of the SCIPS architecture uses the platform of functionalities divided into logical layers with standardized interfaces. So it offers more flexibility and ability to be maintained, since changes in one logical layer do not have consequences on other layers, as far as the interfaces between layers are not changed.

Fig. 1 presents the links of SCIPS with the elements of its environment and its general architecture in water supply system, which consists of four main layers (systems) for:

- Processing Drinking Water Needs - collects and processes the data that depend directly on the user.

- Research and Information - monitors and draws conclusions about the events that directly affect drinking water resources and their availability. Monitoring includes monitoring of the *internal environment* (the focus is on the internal processes and elements that are controlled by the cadastral department at the national level), the *external environment* (includes events outside the cadastral department, which apply to all land plots included in the National Spatial Plan with sources and facilities for drinking water processing and distribution) and the links between urban-cadastral departments at lower levels (e.g. at the municipal level).

- Decision Support (DS) - solves complex problems using analytical modelling, based on an appropriate base of relevant information and, accordingly, includes: the basic documents that contain both internal and external data for analytical modelling, documents containing key factors and data about policy and parameters that determine the operational policy for the drinking water resources management of each functional area, documents with analysis that are matched to future analysis, etc.

- Reporting - creates operational and control reports for planning, control and management of drinking water resources, water supply planning and analysis of costs, budget and performance.

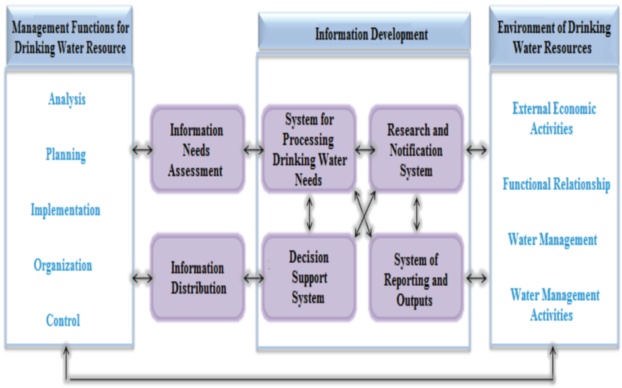

Fig. 1. General architecture of SCIPS and interactions with elements of its environment.

B. *Basic Functions of SCIPS*

The basic functions of SCIPS are input and processing of data, as well as generation, presentation, storage and control of output information. Prior to data input is their collection and preparation for processing, while the results of processing are used by state institutions and agencies (e.g. cadastral department within the municipal authority) within SCIPS, and also can be stored and later used as new inputs to realize certain activities. Information storage is realized in an ordinary manner to be later retrieved and used as inputs for some task in the water supply system. Output information is presented to users in the form of messages, reports, forms and graphic formulation, which is adapted to the situation and the drinking water management field in which they are used.

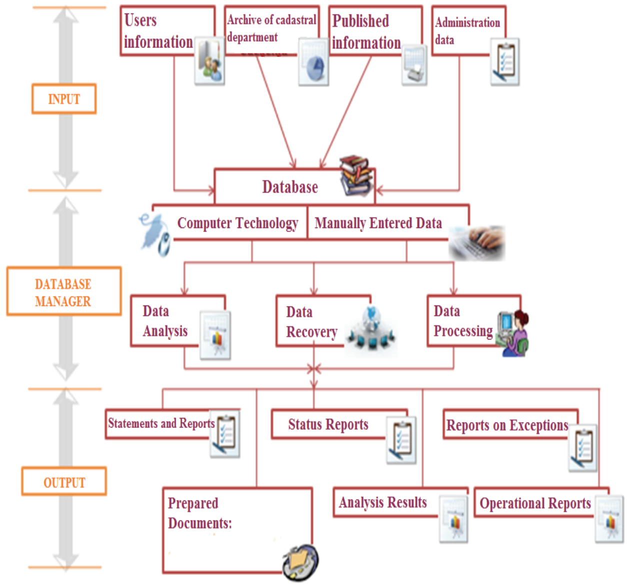

Fig. 2. Basic functions, equipment and data in SCIPS.

Using a functionality of SCIPS is based on the following principles:

- There is no single legal owner (as with the Internet portal), but all subjects in it are owners of their (local) information-technology resources.
- Information in state ownership is available to authorized entities within the system without compensation, unless a special permission is required, for security reasons.
- Hydro-meteorological information that is collected by monitoring the environment, and that is state-funded, represents public property and is available to all authorized entities in the system.
- Hydro-meteorological information collected by state institutions based on the orders of certain entities is not public, i.e. is available to other entities only with the approval of its customer.
- Information that is not owned by the state is arranged by a funding source.

III. Model of Drinking Water Resources Management Based on SCIPS Platform

Annex VII of the European Water Framework Directive obliges the responsible entities to create a management plan for major river basins. That plan, inter alia, envisages the mapped view of surface and ground water of the basin, mapped view of protected areas, a cadastre of pollutants, a register of all plans and programs for watershed management, all water units intended for human consumption, monitoring of all water flows greater than 100 m^3 per day, etc. The operational model of centralized drinking water resources management on the platform of SCIPS provides a proactive collection of spatial and other relevant data using the sensor technology, global navigation satellite systems (GNSS) and wireless communication. In addition, to increase the efficiency of information exchange in interactions of social, public and private agents, usage of SCIPS establishes interoperability of information systems of different organizations and institutions, whose spatial dislocation makes it necessary to use a web-communication technology platform, together with SII. In that context, the SII represents a digital collection of all sources of geo-information that empowers SCIPS in collecting relevant data for an adequate water supply process. [12] On the other hand, web-communication technologies make transparent presentation of information relevant to the management of these resources. Flexibility, as an unavoidable feature of SCIPS allows rapid adaptation to changes in the environment (e.g., drought stress during summer period) and retrieving relevant information from a database, for all levels of decision-making.

The model of drinking water resources management requires, among other things, a SCIPS to include: a general description of the characteristics of the water area, a map of monitoring network, identifiers of institutions and facilities used for water supply, the register of protected areas, etc. It is obvious that the SCIPS includes a larger number of registers with different information contents which is why it is important to define which content belongs to which register, that is, to fully define the key registers. [12]

A. Key Registers in the Model of Drinking Water Resources Management

The role of key registers, as an important component of the model, must be thoroughly investigated, particularly because of their strong links with other registers in the SII, particularly spatial (e.g. topology, roads) and administrative (e.g. utilities companies, addresses, institutions, etc.). This means that unambiguous definitions of the content for all key registers are needed in order to avoid overlap and enable the reuse of information in other external registers. In addition, by continuous updating of these independent, but in some way connected registers, the maintenance of consistency is enabled, not only in one register, but also between them. [3]

This allows refinement of geometric shapes of objects and addition of key information (attributes) that connect each object with its description in the home and external registers. [12] For example, some attributes of the concept, that is, object “springhead” are the name, coordinates, elevation, yield, quality, distance from water supply network, etc., while the attributes of the object “mountain stream” are name, a sub-basin, catchment area, elevation of the source and mouth, length and minimum length of flow, the coefficient of the flow development, total and average drop, etc. Association of attributes with objects, phenomena or processes represents the source of undisputed great importance and influence of the key registers in drinking water resources management.

It also involves the creation and indivisibility of the attributes that characterize drinking water as a resource, through the matrix quadruplets:

$$VR= ((L,Q,Q_0),US), \qquad (1)$$

where the attributes are location (L), quantity (Q), quality (Q_0) and the existence of conditions for use (US). For that reason, various registers are interconnected, i.e., there are references in the contents of one register to another register. When these connections are once established, it is possible to obtain all the attributes of a selected object, or vice versa, locate objects in space based on defined attributes. Since the relationship between objects and their attributes has a dynamic character, and the registers are held by a number of autonomous organizations and institutions, great attention must be paid to the updating of information in order to trigger potentially related updates in other registers. Unambiguous specification of data for the key registers themselves is necessary, as well as the determination of their boundaries and maintaining consistency between them after the update. It is also necessary to determine how to achieve harmonized specifications of data in the registers, where special attention must be paid to the following categories of data: Geographical and Topographical Data; Data on Infrastructure Facilities in the Field of Water Supply and Utilities; Data on the Status of Surface and Ground Water; Data Related to the General Requirements of the Aquatic Environment, survey results, the emissions and measured data; and Data on Users of Drinking Water, interest groups, institutions and public. Therefore, the contents of the key registers are the first thing to investigate and reach a consensus about them. Some of the possible key registers that are associated with the model of drinking water resource management are:

- Cadastral (land) Register.
- Register of Persons (e.g. customers, competent and responsible persons, etc.).
- Register of Companies, Institutions, etc.
- Register of Traffic Infrastructure Objects.
- Register of Descriptive Data (nature, size, value and legal rights or prohibitions associated with each registered object).

All these registers can be used, for example, for purposes of referencing (or as a support for data input) in the model of drinking water resources management. However, such their use requires some semantic agreements between the "split" concepts or at least interfaces and object identifiers. [12] In other words, all the above registers must be harmonized, based on the established agreements on the use of concepts and their semantics.

B. *Interactions Included in the Model of Drinking Water Resources Management*

Interactions in the model and with the model occur during the collaboration of SCIPS with external nodes in drinking water resources management, for example, agents from other economic systems. They are implemented to harmonize the activities and work flows in the case of using the same resources (e.g. a particular infrastructure object) by the water supply system and other business systems. In such a case, two basic elements which are involved in drinking water resources management are considered:

- SCIPS - corresponds to the management function in the flows of cadastral data related to objects in water supply system, and
- Executive Information Systems - include resources and business logic of the Department of Utilities, Department of Physical Planning, Department of City Development and Department for the Management of Traffic Flows, the Tax Department and others.

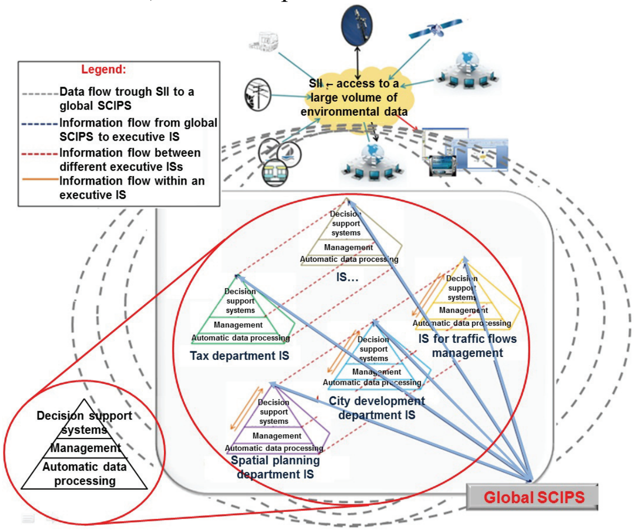

Fig. 3. Relation of SCIPS and other executive information systems of the state.

Fig. 3 visualizes the relationship of SCIPS and other state executive information systems. SII, executive information systems and SCIPS are vertically integrated, meaning that there is a vertical flow of information between levels. Information that flows from a lower level is input data to the information systems at a higher level [8]. The information that flows from higher levels is a managerial decision for lower levels. On the other hand, horizontal integration in this case involves information flows at the same level of decision making.

IV. Semantic Synchronization of Key Registers within the Model of Drinking Water Resources Management

A good and actual way to achieve semantic synchronization of key registers within the model of drinking water resources management is provided by ontological engineering. Ontologies are an essential tool for designing a domain model or for the development of knowledge based systems. According to the most general and most performed definition, ontology is a formal, explicit specification of shared conceptualization. The conceptualization refers to the abstraction of a phenomenon by identifying its relevant concepts. That means that this type of concept is used and that the constraint on its use is explicitly defined, and formally refers to the fact that the ontologies should be machine readable. In this context, ontologies can be imagined as semantic primitives that specify a single domain of knowledge. The main advantage of the existence of such specification is facilitated knowledge sharing and reuse between different interested parts in a specific knowledge domain [2].

Using ontologies and ontological engineering techniques, there can be established semantic references between different registers within the model of resource management of drinking water, both at the structure level and at the level of content. Semantic synchronization of key registers in the model can be viewed as a process to harmonize the different structures or contents of the elements among the registers, that is, domain ontologies.

The starting point for the process of semantic referencing of registers within the model of drinking water resource management is the initial reference point, which can be established using automated tools. The process is iterative and is performed every time when new references about drinking water resources are added in the reference warehouse or when using the existing references that are estimated by the user. Accordingly, the system is self-learning and over time it will adapt the collection of references on drinking water resources. The process as a whole is the basis for the realization of semantic synchronization of various registers within the model in any type of application.

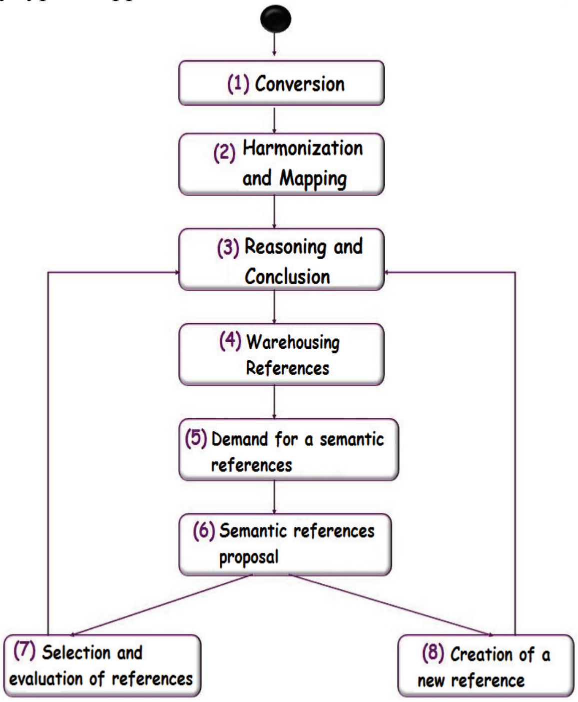

Fig. 4. The adjustment process of semi-automated semantic referencing of key registers in the model of drinking water resources management.

Customizing semi-automated semantic referencing of key registers in the model of drinking water resources management is carried out through eight steps.

Step 1 - Conversion: Since the databases in SCIPS can exist in different formats, they can be syntactically heterogeneous. For example, the standards for data exchange that are in frequent application are available in formats such as XLS, CSV, XML, XSD, etc. To make them suitable for processing they need to be reduced to the general syntax format, and we need to use the tools of ontological engineering for their conversion into ontologies. For documents based on XML, an XSL transformation is used (eXtensible Stylesheet Language Transformations), by which ontologies are converted into an OWL format. Similar mechanisms can be applied to other structured formats. On the other hand, if the knowledge of drinking water resources is available in an unstructured format, such as the language in a text document or Web pages, to convert these descriptions into ontologies, we can apply the mechanisms of ontology learning.

Step 2 - Adjustment and mapping: This involves finding semantic references between the elements of structured knowledge bases in SCIPS. This step requires the dimensions of the semantic similarity of the entities of two or more ontologies and implementing the specification of semantic relations without merging ontologies or modification of some of them. Creating the initial set by mapping between the data exchange standards can be achieved by using automated processes. On the other hand, for processing and combining the existing knowledge we can use the methods and techniques of ontological engineering and artificial intelligence. In order to improve the quality of the mapping and to facilitate the resolution of ambiguity of the specification of the data needed for the key registry of the model, in the adjustment operations can be included reference ontologies as well. That can be the so called top-level ontologies which include the entirety of knowledge from multiple domains, that is, which represent a combination of different domain ontologies [11], and some of them are: OpenCyc, open-source version of the general knowledge base CYC, Ontology for knowledge representation (KR), Suggested Upper Merged Ontology - SUMO, Descriptive Ontology for Linguistic and Cognitive Engineering (DOLCE), Common Warehouse Model (CWM) of metadata.

Step 3- Deduction of new knowledge: After drinking water resources references formation in step 2, they can be employed to conclude new references, and the possibility of deduction of the statement makes formal semantics easier. If the representative language of the ontology is semantically expressive enough, it is possible to divide objects into classes, and further classification into subclasses and their equivalents. It is important to emphasize that the complexity of the concluding process and efficiency of the algorithm directly depend on the ontological language itself.

Step 4 - Storage: Mapping results are stored in the storage of drinking water resources references and create long-term semantic relations. The benefit of a collection of references on those resources increases further with the iterative addition of references. The references between different registers can be created, modified or deleted within the warehouse, while the standards are kept in their original form.

Steps 5 and 6 - Preparation of references: The warehouse of drinking water resources references provides answers to a query or a request of a user for semantic references. It is available and accessible by sending direct requests from another application or using a web interface. The system searches the knowledge base as a dictionary, and allocates machine-generated proposals and presents to the user for selection, and then automatically compiles a list of appropriate references. From that list, the user can select a drinking water resources reference, and in the case when the proposals are not considered suitable, he/she can create a new reference. Optionally, the user can proceed without selecting a reference from the list.

Steps 7 and 8 - Assessment and creation of new references: The semantic heterogeneity of different registers that are used in the model of drinking water resources management often cannot be resolved in a fully automated way. With the semi-automated approach, semantic references are subject to user validation. By manual intervention it is possible to solve the problem of ambiguous specification of the relevant data which is necessary for the registers themselves. Experience with the existing tools of ontological engineering shows that knowledge of experts on the observed domain of water supply processes is still necessary in order to achieve a high level of quality of drinking water resources mapping within key registers.

V. Conclusion

Water as a living, but also a business asset has its value and its price, which requires its measurement in the process of marketing. At this level, drinking water resources are much underestimated, because they really have the greatest value, but their measurement (at least with us) is insufficient. It is a recurrence of the time in which water was treated as an asset which can be used without any licenses and material commitments, while used and polluted water was run off where it is most appropriate, without any control. There is also the problem of an insufficient number of places where flows in a hydrographical network are measured, often with interruptions, and by methods that do not allow the use of this information for operational decision-making. The solution is in the digitized process of drinking water resources managing from the state, through the entity, to the local level. In our country there is still no unified strategy or coordination between the subjects, which becomes absolutely untenable in terms of integrated management of these resources, which are prescribed by the European Directive on Water.

The modern concept of drinking water resources management is based on the full hydrologic, hydraulic and qualitative visibility of all resources in the water supply system and sets new goals, principles and standards in creating policy, as well as new requirements for the necessary environment (political, legal, organizational, financial, etc.) in which it has to be implemented. In that context, the role of ICT, SII and integration and multiple uses of relevant data in activities that contribute to the implementation of the policy of integrated resource management is emphasized.

The suggested model of drinking water resource management on the platform SCIPS, with the semantic synchronization of key registers in it, will support more rational and sustainable use of these resources, and enable avoiding potential conflicts of interest or jurisdiction over them. The application of modern technologies, ontologies and key registers, required by the model, in the processes of measuring, collecting and processing data, as well as planning, management and decision making, will also enhance the forecasting process, especially from the aspect of the integration of stochastic phenomena and processes in drinking water resources management. This is very important because the complete identification and more accurate assessment of possible risks in water supply are very important for decision making in different areas of drinking water resource use and protection, and may also affect the acceptance or rejection of projects or plans for protection of the entire population and ecosystems.

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